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Quantification and monetization of employment benefits associated with renewable energy technologies in Greece

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ABSTRACT

This paper formulates and implements an integrated approach for estimating the employment benefits associated with the exploitation of renewable energy sources (RES) in the power sector. It builds up on well-known techniques and makes all the necessary modifications in order to take into account the specific conditions of the RES market. More specific, the proposed approach exploits the input–output methodology for estimating the direct, indirect and induced employment effects associated with the energy technologies in question and the "opportunity cost of labour" approach for expressing these effects in monetary terms. This framework has been implemented to estimate the employment benefits resulting from the development of different RES technologies in Greece, taking into account both the construction and operation phases of the relative projects. The results of the analysis clearly show that the exploitation of RES in the Greek power sector presents significant employment benefits, which are at the same order of magnitude or in several cases even higher compared to the corresponding benefits attributed to the operation of fossil-fueled power plants (e.g. lignite and natural gas). Therefore, the fulfillment of the national target for increasing the penetration of RES into the Greek power sector from approximately 12% today to 40% in 2020, will contribute, apart from the significant environmental improvements, to the overall economic development and the increase of the employment.

Contents

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1. Introduction

Creating new jobs and combating unemployment are nowadays increasingly considered as a positive externality, although many economists still disagree with this view claiming that in perfectly competitive markets the existence of any unemployment represents temporary situations, in which individuals change their professional status in order to find a better position in the labour market or to obtain additional skills and as a result unemployment does not impose any social cost [1,2]. Saez et al. [3] sustain the view that in economies presenting low unemployment rates (i.e. 3–5%) the increased demand for jobs due to an investment will be only realized as a change in the allocation of jobs and will not result in a net increase of the people employed. However, during the last decade unemployment appears as one of the most significant problems in society and provokes intense worries in presently employed individuals. Nowadays, boosting employment through the adoption of effective policies is a priority for most developed countries and it is logical to assume that the creation of new jobs in economies with unemployment rates higher than the natural level of 3–5% results in significant social benefits. In fact, to get these benefits, governments are willing to undertake considerable efforts and to spend huge financial resources [3].

It is widely acknowledged that the move towards a green economy will create a large number of new jobs across many sectors and will act as a vital stimulus to sustainable development. In particular, the exploitation of renewable energy sources (RES) in power generation is expected to have a substantial contribution to the overall rise of employment opportunities in several sectors including equipment manufacturing, construction, administrative and service activities.

The above considerations explain the growing interest in measuring and valuing effects on employment produced by renewable energy technologies and relevant development paths. In the study of EWEA [4], the employment created by the exploitation of wind energy in Europe has been assessed, while Kammen et al. [5] presented a review of studies estimating the employment effects (direct and indirect) in physical terms for renewable energy technologies and accordingly assessed scenarios for their penetration in USA. BMU [6] examined the impact of the expansion of RES on the German labour market, by distinguishing between direct and indirect employment effects and RWI [7] updated these estimates on the basis of available studies pinpointing that the positive employment effects critically depend on a robust foreign trade of renewable energy technologies. Lehr et al. [8] implemented a study that modelled positive impacts (including employment effects) of an increasing share of renewable energy on the mitigation of climate change. UNEP [9] estimated the future green employment in a sustainable, low-carbon world providing estimates for employment effects in physical terms for various countries (Germany, Spain, USA and China), while Greenpeace [10] calculated on the basis of existing studies the new direct and indirect jobs expected to emerge in Greece due to a future deployment of renewable energy technologies. In the study of European Commission [11] the economic effects of supporting RES in EU were assessed for selected scenarios for RES deployment taking into account the direct and indirect impact on all sectors of the economy. Sastresa et al. [12] applied an integrated methodology to the autonomous community of Aragon (Spain) in order to assess the impact of RES on the jobs created, the quality of the jobs and other factors related to the socio-economic development of the region: technological development, per capita income, territorial and human capital development. Finally, the study of Pollin et al. [13] provided quantitative estimates for the direct, indirect and induced employment associated with two governmental initiatives in the USA, which comprise considerable investments in renewable and other clean energy technologies and practices.

Obviously, fewer studies have attempted to quantify in monetary terms the employment benefits created by renewable energy technologies or in general by energy investments. ORNL and RFF [14] assessed the employment benefits of the coal fuel cycle by using of the "opportunity cost of labour" approach, taking into account both direct and indirect employment. The economic valuation was performed on the basis of the net income increase for newly employed workers and the value of potential losses of their leisure time. Saez et al. [3] in Spain and Faaij et al. [15] in Netherlands analyzed comparatively the employment benefits associated with coal and biomass fuel cycles. The valuation was based on specific assumptions as regards the expenses undertaken to avoid unemployment in the form of unemployment subsidies, governmental programmes to reduce unemployment, etc. European Commission [16] assessed the employment benefits associated with the hydro fuel cycle at both local and national levels following a similar approach and using implicit valuation techniques based on revealed preferences of the government to create extra employment. Markandya [2,17] proposed a methodological framework for assessing the employment benefits derived from energy projects by taking into account the net gain of income, the value of any lost leisure and the health-related impacts associated with unemployment.

Another approach for the economic valuation of employment impacts is the exploitation of stated preferences techniques. In the RECaBS (Renewable Energy Costs and Benefits for Society) IEA's project [18], an interactive renewable energy calculator is provided for estimating costs and benefits of electricity from RES compared to fossil fuels, with the monetary values assigned to employment effects reflecting the society's willingness to pay for the creation of local jobs. These estimates were derived from the studies of Moos [19], for the implementation of rural job creation programmes in Denmark from 1994 to 1999, and from Roy and Wong [20], which is an evaluation report of 25 years of Canadian direct job creation programmes. Another similar attempt is the study of Solino [21] who analyzed the willingness to pay for a programme that promotes the production of electricity from forest biomass, instead of fossil fuels. The associated employment benefits have been monetized by implementing a choice experiment method.

Finally, in the study of URJC [22], the increase of direct and indirect employment in Spain caused by the exploitation of RES in electricity production was valuated by using two different methods. First, the average amount of the necessary subsidized part of the investment to create a green job was compared with the average amount of capital required for establishing a job in the private sector. Secondly, the average annual productivity of each subsidized green job was compared with the average productivity of labour in the private sector that allows workers to remain employed.

In our previous work, we have developed a sound methodological framework that was implemented for the quantification and monetization of employment benefits associated with two conventional power-generation technologies used in the Greek interconnected power-generation system, namely lignite condensing and natural gas combined cycle power plants [23]. In the present paper this framework is extended to cover also RES and updated by using a more recent version of the input–output table for the Greek economy. Moreover, it is suitably adapted for the case of insufficient or less reliable data on employment, as is usually the case for RES projects. The produced estimates can be exploited in policy making, by means of a cost–benefit analysis or other assessment procedures, resulting in the improvement of energy planning processes.

The structure of this paper is as follows: Section 2 describes the methodological approaches used in this paper. In Section 3,

the proposed methodological framework is applied to estimate the employment benefits associated with the power-generation technologies in question. The uncertainties of this analysis are highlighted and a sensitivity analysis is carried out in Section 4. Finally, in Section 5 the main findings of the study are summarized and conclusions are drawn.

2. Methodological framework and basic assumptions

The methodological approach used in this paper is divided in two major parts. Firstly, employment effects will be measured in physical terms, while in the second part the benefits from the created employment will be translated into monetary terms that can be directly incorporated in a cost–benefit analysis.

2.1. Quantification of employment effects

Employment effects created by any economic activity are divided into three distinct categories: direct, indirect and induced. More specific, the direct employment effects associated with the development and operation of RES technologies are those created in the various activities of the corresponding fuel cycle (i.e. manufacturing of the equipment, construction of the power plant, fuel extraction, collection and transportation, operation of the units, etc.), which are undertaken locally or nationally and directly contribute not only to the level of employment but also to the overall economic development. The realization of all these activities requires the purchase of goods and services such as construction materials and equipment, maintenance services, supplies, equipment and manpower essentials like food and clothing. These additional expenditures will generate new jobs in all sectors of the economy, known as indirect employment. Furthermore, as those engaged directly or indirectly in the project activities will increase their available income for spending, additional economic development and employment is expected due to the increased consumption for purchasing goods and services. For instance, employees in the power sector who use their income to buy various commodities or to provide entertainment for their families generate economic impacts for workers and businesses in those sectors. These individuals will, in turn, spend their income much like the employees in the power sector do. This cycle continues until spending eventually leaks out of the local/national economy, creating an additional number of new jobs, known as induced employment.

The approach developed to quantify the direct, indirect and induced employment effects associated with the examined renewable power generation technologies is based on input–output analysis and is analytically described in the following paragraphs.

2.1.1. The input–output methodology

Input–output analysis is a well structured methodological approach, which can assess the effects of a project or a policy on key socio-economic variables, taking into account the inter-sectoral linkages in an economy. More specific, input–output tables provide a complete picture of the flows of products and services in an economic system for a given year, illustrating the relationship between producers and consumers and the exchange of goods and services among economic sectors. In other words they illustrate all monetary market transactions between various businesses and also between businesses and final demand sectors (i.e. consumers, government, investment, exports, etc.). Thus, they can be used to construct disaggregated multipliers in order to estimate apart from the direct impacts of a particular policy or project, also its indirect and induced impacts. This is accomplished through the use of the Leontief inverse matrix [24,25]. The standard representation of the input–output model in matrix notation can be defined as follows:

$$X = (I - A)^{-1} Y \tag{1}$$

where

X is the vector of final production of the economy in question.
Y is the vector of final demand of the economy.
A is a $n \times n$ matrix of technical coefficients. A technical coefficient a_{ij} is defined as the amount of production of sector i that sector j requires to produce one unit of output. Through these coefficients one can estimate the direct impacts from an increase in final demand for a particular commodity on the various economic sectors.
I: is the identity matrix.
The $(I - A)^{-1}$ is the $n \times n$ matrix of input–output multipliers, or the Leontief inverse. The rows and columns of the Leontief inverse matrix are the sectors of the economy and each element b_{ij} of this matrix shows the total required increase in the production of sector i to meet an increase of one unit in the final demand of sector j. The sum of all the elements of the j column of the Leontief inverse matrix gives the output multiplier of the sector j. The output multiplier for the j sector is the total change in gross output (or sales) of the entire economy by an initial change in the final demand in sector j of 1 €.

There are two types of Leontief inverse matrices. The first, named Type I, includes only the relationships between the various economic sectors and is used to estimate the indirect economic effects. The second, named Type II, includes also the effect of households' consumption (by expanding the matrix with one column, namely the households' expenditure and one row, namely the compensation of employees) and is used in conjunction with Type I Leontief inverse to estimate the induced effects of a policy or project.

At this point it is worth mentioning that the utilization of input–output tables as a generic tool for analyzing the macroeconomic impacts of different policies or investments can only be done under specific assumptions and prerequisites [26]. The first of these assumptions, called the homogeneity assumption, postulates that:

(i) each sector produces a single output (i.e. all the products of the sector are either perfect substitutes for one another or are produced in fixed proportions),
(ii) each sector has a single input structure (i.e. it does not vary in response to changes in product mix), and
(iii) there is no substitution between the products of different sectors.

The second assumption, called the proportionality assumption, postulates that the change in output of an industry will lead to proportional changes in the quantities of its intermediate and primary inputs, while the third assumption, postulates that the production process of each sector does not affect the production activities of any other sector. Even though these assumptions are far from being realistic given the multiplicity and variability of processes in modern economies, input–output analysis is still considered as an attractive and powerful tool that is capable of adequately capturing the interlinkages within a national economic system. Moreover, since radical changes in economic structure can be assumed to occur relatively slowly, the results derived from such models can remain robust for many years [27].

2.1.2. Direct employment effects

Obviously, the most straightforward way to assess the direct employment effects is to collect employment data directly from

the units involved in the considered activities, as was done in our previous work focusing on employment from lignite- and gas-fired power plants [23]. However, in most countries the number of operating RES units and of other related RES cycle activities are still few and reliable data as regards employment inputs are missing or vary significantly from case to case. Therefore, the estimation of direct employment in physical terms was performed using purely financial data on the distribution of cost among various activities for each renewable energy technology and exploiting the input–output table of the economy in question. Specifically, the analysis focuses on (a) the investment cost which is composed by the cost of equipment, the cost of civil works, the cost of mechanical support, the cost of transport, etc., and (b) the operational and maintenance cost which is basically composed by labour cost, financial and other services, as well as by machinery and devices.

Each cost category is assigned to a number of distinct economic sectors that are included in the input–output table, which are characterized by the following 2 indices: total production, P_j and total employment, E_j. Hence, it is assumed that the marginal growth MP_j in the activity of sector j caused by the realization and operation of the RES project incurs an analogous increase in the level of direct employment ME_j that can be approximated by the following simple formula:

$$\mathrm{ME}_j = \mathrm{MP}_j \cdot \frac{E_j}{P_j} \tag{2}$$

It is clear that total direct employment caused by the realization of a RES project results as the sum of all marginal increases in the activities involved in the construction and operation of the RES power unit under consideration.

As expected, the largest share of the total investment cost of RES technologies refers to the cost of equipment. Thus, in order to estimate the local or national economic impacts of the RES development in a region or country, one has to take into account to what extent the production of the equipment (and thus the relative expenditures) occurs inside the economy or they are imported from abroad. In the latter case the analysis should be based only on this part of the expenditures that are spent inside the economy in question. This is, for example, the case of wind turbines in Greece. Within the EU, wind turbine manufacturing activities and therefore employment in manufacturing is concentrated in a few countries, with Germany, Denmark, and Spain accounting for more than 90% [4]. At this time, most of the manufacturing of specialized components of wind turbines installed in Greece takes place abroad and therefore the associated employment benefits in the national economy are relatively limited. However, the scheduled development of wind energy in Greece (the total installed capacity is expected to reach 7 GW in 2020 compared to approximately 1 GW today) may give the opportunity to develop a wind turbine manufacturing industry in Greece maximizing the national employment benefits from this type of investments.

2.1.3. Indirect and induced employment effects

The indirect and induced employment effects associated with RES utilization are also estimated through the exploitation of input–output analysis.

Knowing the sectoral employment of the economy under consideration, the Leontief inverse matrix can be used to estimate the total employment effects of a policy or investment, through employment multipliers. The employment multipliers measure the total change in employment resulting from an initial change in employment as a result of the change in the output of one or more economic sectors. Consider, for example, the realization of a project hiring 100 new employees. If the estimated employment multiplier of the corresponding economic sector is 2.5, then $(2.5 - 1) \times 100 = 150$ additional jobs would be created in the entire economy as a result of the 100 new jobs in the reference project.

As already mentioned, two types of multiplier could be estimated:

- The Type I employment multiplier is the ratio of direct plus indirect employment change to the direct employment change:

$$W_j = \sum_{i=1}^{n} \frac{e_i b_{ij}}{e_j} \tag{3}$$

  where W_j is the Type I employment multiplier for sector j, e_i (or e_j) is the employment per 1 € of total output per sector and b_{ij} is the Type I Leontief coefficient identifying the direct and indirect effects on the demand for the output of industry i as a result of changes in the demand of industry j.
- Similarly, the Type II employment multiplier (W'_j) measures the ratio of direct, indirect and induced employment change to the direct employment change:

$$W'_j = \sum_{i=1}^{n+1} \frac{e_i b'_{ij}}{e_j} \tag{4}$$

  where b'_{ij} is the Type II Leontief coefficient.

Given that according to the methodology presented in the previous section the direct employment associated with the development of a RES project is estimated as the sum of the employment created in a number of distinct sectors of the economy in question, the resulting indirect and induced employment effects can be easily estimated through the Type I and Type II employment multipliers of those economic sectors.

2.2. Economic valuation of employment benefits

Once the direct, indirect and induced employment effects associated with a RES project have been quantified, their economic valuation is very important in order to be easily incorporated in cost–benefit analyses. In the proposed methodology by Tourkolias et al. [23] the economic valuation can be undertaken on the basis of two different approaches, namely the “opportunity cost of labour” approach and the “public expenditures” approach. The former is based on a more comprehensive theoretical background, classified in the category of revealed preferences methods for the monetization of environmental and social goods and is used in the context of this study for the base case analysis. The latter can be considered as a proxy method for the monetization of social goods and is exploited in this study for sensitivity analyses.

Theoretically, in fully competitive conditions the market prices are specified according to corresponding opportunity costs. Analogously, in the labour markets, the wage of a newly employed person should be equal to the opportunity cost of labour and therefore there are no social benefits resulting from the creation of new employment. However, this is a quite theoretical scheme and nowadays the reality in both developed and developing economies shows that the creation of employment results in social gains. More specific, in markets with high rates of unemployment there is a probability (P) that the worker who is hired in a new job, which is created in the economy due to an investment, will be drawn from the pool of previously unemployed workers. Alternatively, there is a probability (complementary to the previous one) that the worker will be drawn from other existing employment. These two options result in different social gains. According to Markandya [2], the following parameters should be taken into account in an integrated assessment of the social gains associated with the creation of new employment.

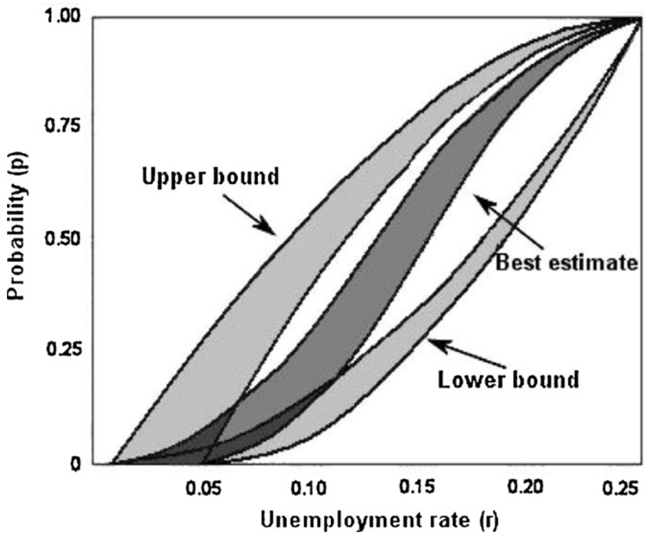


Fig. 1. Distribution of the probability, a newly employed person to be drawn from the pool of previously unemployed workers in relation to the unemployment rate of the economy.
Figure derived from Haveman and Krutilla [28].

- The individual's income as a result of the new job (CI).
- The loss of income (PI) that the individual had at his or her disposal due to the previous employment status (e.g. wage from the previous work, unemployment benefits, and income from informal employment that cannot be continued).
- The value of the time (L) that the person had at his or her disposal in cases that he or she was previously unemployed.
- The value of health-related consequences (stress and stress-related factors, consumption of tobacco and alcohol) associated with unemployment situations (H).

The analysis of the possible employment benefits associated with the examined energy investments is restricted to the cases that newly employed workers are drawn from the pool of workers who were previously involuntarily unemployed. As already mentioned above, benefits also exist in cases that the new job is filled by a worker that previously had another job, but since their estimation require making certain assumptions about the previous work of the employee, they have been ignored in the present analysis. So, the employment benefits (B) can be estimated through the following formula:

$$B = P \cdot (CI - PI - L + H) \quad (5)$$

The main assumptions of this study for the key parameters of the analysis are briefly presented below. Firstly, an important part of the proposed methodology is the estimation of the value of the possibility (P) the newly employed workers to be drawn from the pool of workers who were previously unemployed. This possibility depends on the unemployment rates of the economy that the new job is created and ranges between 0 and 1 as displayed in Fig. 1 [28].

The utilized procedure is based on the assumption that if the unemployment rate of the economy is close to the natural rate of unemployment (e.g. 3–5% or even lower) the P equals to 0 and all new jobs created by the investment in question will be covered by already employed persons. On the other hand if the unemployment rates of the economy are very high (e.g. 25%) then P takes a value close to 1 and it is considered that all new jobs created by the investment in question will be covered by previously unemployed workers. The value of P is calculated with the function proposed by Haveman and Krutilla [28] for levels of unemployment between these two extremes.

Another crucial parameter of the methodological framework is the increase of personal income from individual's movement from unemployment to employment. The estimation of the income will depend on the new, net of tax, wage reduced by unemployment compensation and other benefits that were available during the phase of unemployment. In the context of this analysis, the assumptions which have been made to estimate the net income are identical to these which made in Tourkolias et al. [23].

Finally, the assumptions regarding the economic valuation of value of lost leisure and health-related impacts remained identical with the corresponding in the study of Tourkolias et al. [23]. More specifically, the value of non-working time equals to 15% of the gross wage for an initial approximation of the benefits of employment, while the excess death rate among the unemployed people is 1.69 deaths per 1000 of population and the health benefits associated with the creation of employment due to the realization of a project are calculated by multiplying that change in risk of death by the "Value of Statistical Life" (VSL), which has been taken equal to 1,000,000 €.

3. Implementation of methodology in Greece

3.1. Quantification of employment effects

In the context of this study, the direct, indirect and induced employment effects associated with the development and operation of the examined RES technologies in Greece are estimated through the most recent input–output table for the Greek economy, which refers to the year 2005. It is worth mentioning that the construction and operation activities of each specific RES technology in question are not included as distinct sectors in this table. Therefore, as described in the proposed methodological framework in Section 2, the analysis is undertaken by disaggregating the expenses associated with the development and operation of each examined RES technology to the predefined economic sectors included in the input–output table. Aiming at reducing the amount of data and the assumptions required as regards the analysis of spending for each RES technology, the 30 × 30 input–output table of the Greek economy has been chosen for the quantitative analysis instead of more detailed ones. Table 1 summarizes the analysis of spending for the development and operation of all RES technologies examined in the context of this study. These distributions are based on literature review [13,29–31] as well as on data from the development and operation of real relative projects in Greece.

Moreover, the necessary techno-economical data, which were used for the estimation of the total amount of spending for the examined RES technologies, are presented in Table 2.

As already mentioned in the methodology, a key assumption of this analysis is to what extent the necessary equipment for the development of the various RES projects is manufactured domestically or is imported from abroad. At the moment Greece has a significant production industry as regards solar energy, while the majority of the equipment associated with other RES technologies is imported from other countries. However, according to the National Renewable Energy Action Plan [32] the installed capacity of all examined RES technologies in Greece will be significantly increased in the upcoming decade with a view the country to fulfill its mandatory targets stemming from a number of European Directives in the scope of the 20–20–20 by 2020 package announced by European Commission in January of 2008. This offers considerable chances for the establishment of a domestic industry as regards the production of RES equipment in Greece, taking of course into account the structure and productive capacity of the existing industrial sectors. So, in our base case analysis it is considered that at a first level the 100% of the spending associated with the

Table 1
Distribution of spending for the development and operation of the examined RES technologies.

	Wind		PV		Hydro		Geothermal		Biomass	
	Construction	Operation	Construction	Operation	Construction	Operation	Construction	Operation	Construction	Operation
Mining and quarrying products							17.5%			
Rubber and plastic products	12%	5%								
Basic metals and fabricated metal products	12%		14%		2%		16%		5%	
Machinery and equipment	37%	30%	49%	15%	23%	35%	33.5%	35%	40%	15%
Electrical machinery	6%	15%	14%	15%	5%	15%	5%	15%	10%	5%
Construction Work	26%		20%		60%		20%			
Hotel and restaurant services	0.5%	2%							40%	
Trade Services										30%
Transport, post and communication services	1%	1%	0.5%		1%				0.5%	40%
Financial intermediation services	0.5%	17%	0.5%	50%	1.5%	20%	1.5%	20%	0.5%	
Real estate, renting and other business services	5%	30%	2%	20%	7.5%	30%	6.5%	30%	4%	10%

Table 2
Data used for the estimation of the total spending for the development and operation of the examined RES technologies.

	Wind	PV	Hydro	Geothermal	Biomass
Inv. cost (€/kWel)	1300	3000	1500	2200	3300
O&M cost (of inv. cost)	4%	1%	4%	3.7%	7%
Load factor	25%	16%	40%	70%	70%
Lifetime (years)	25	20	50	35	35

Table 3
Estimated employment effects related to the utilization of RES technologies in Greece (in man-years/MW).

	Wind		PV		Hydro		Geothermal		Biomass	
	Construction	Operation	Construction	Operation	Construction	Operation	Construction	Operation	Construction	Operation
Direct	8.8	7.5	17.2	4.1	14.6	16.7	12.9	15.9	25.0	78.0
Indirect	4.8	3.4	9.4	1.6	6.9	7.0	6.8	6.7	12.2	28.1
Induced	3.6	4.1	7.2	2.7	5.5	9.5	5.5	9.0	9.7	29.3
Total	17.2	15.0	33.7	8.4	27.0	33.2	25.3	31.6	46.9	135.3

development and operation of RES technologies is distributed to domestic industries, which at a second level on the basis of their structure described in the input–output table, realize certain levels of imports. An alternative scenario, which assumes that almost entirely the necessary equipment is imported from abroad, is examined as a sensitivity analysis in the next section.

The results of the analysis clearly show that the utilization of all RES technologies in Greece have significant employment implications (Tables 3 and 4). The estimated direct, indirect and induced employment effects range from 265 man-years/TWh in the case of geothermal plants up to 1503 man-years/TWh in the case of photovoltaic units. Most of the employment effects associated with wind farms and photovoltaic units are generated during their construction phase and therefore the resulting benefits are primarily received by the society at an early stage of the entire life cycle of these projects. Particularly for the photovoltaic units, the very high employment effects estimated per TWh of electricity generated, is mainly attributed to the high investment costs and the rela-

Table 4
Estimated employment effects related to the utilization of RES technologies in Greece (in man-years/TWh).

	Wind		PV		Hydro		Geothermal		Biomass	
	Construction	Operation	Construction	Operation	Construction	Operation	Construction	Operation	Construction	Operation
Direct	160.3	136.9	612.2	146.8	83.3	95.4	60.2	74.0	116.3	363.2
Indirect	88.2	61.6	333.7	56.4	39.5	40.2	31.9	31.1	57.0	130.8
Induced	66.3	74.7	255.6	98.0	31.5	54.1	25.8	41.9	45.0	136.5
Total	314.8	273.2	1201.5	301.3	154.3	189.7	117.8	147.1	218.3	630.6

Table 5
Total employment related to RES technologies in Greece on a sectoral basis (in man-years/TWh).

	Wind		PV		Hydro		Geothermal		Biomass	
	Construction	Operation	Construction	Operation	Construction	Operation	Construction	Operation	Construction	Operation
Agriculture, hunting, forestry and fishing	13.4	15.0	46.2	17.4	5.7	9.8	4.7	7.6	8.1	27.0
Mining and quarrying	1.9	0.8	7.6	0.7	0.9	0.6	5.0	0.4	1.3	2.3
Manufacturing	108.0	63.7	477.6	42.7	27.6	42.9	38.8	33.2	57.1	61.9
Electricity, gas and water supply	3.6	2.3	13.9	2.3	1.2	1.4	1.5	1.1	1.9	4.9
Construction	85.3	7.4	295.5	6.8	69.6	5.3	28.7	4.1	83.6	7.6
Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods	40.1	28.1	147.8	28.5	19.3	18.5	14.0	14.4	27.2	244.7
Hotels and restaurants	9.6	16.0	30.8	12.6	3.8	7.0	3.1	5.4	5.4	19.1
Transport, storage and communication	9.6	10.2	32.4	10.1	4.7	5.7	2.8	4.4	6.0	164.4
Financial intermediation	7.6	44.1	29.4	106.5	4.1	36.4	3.9	28.2	4.9	15.8
Real estate, renting and business activities	24.0	71.1	75.9	54.7	12.0	51.5	10.9	39.9	15.0	58.1
Public administration and defence; compulsory social security	0.3	0.4	1.3	0.5	0.2	0.3	0.1	0.2	0.2	0.7
Education	2.9	3.4	11.2	4.5	1.4	2.5	1.1	1.9	2.0	6.1
Health and social work	3.3	4.0	12.6	5.7	1.6	3.0	1.3	2.3	2.2	6.8
Other community, social and personal service activities	5.1	6.7	19.2	8.3	2.4	4.9	2.0	3.8	3.4	11.3
Total	314.8	273.2	1201.5	301.3	154.3	189.7	117.8	147.1	218.3	630.6

tively low load factor that characterize this technology. On the other hand, primarily biomass units and secondarily hydro and geothermal power plants present overall higher employment effects during their operation phase compared to their construction. Particularly for biomass case study this is mainly attributed to the considerable expenses required for biomass collecting and transportation for the feed of the power plant.

The estimated indirect and induced employment effects for all examined RES technologies are almost at the same order of magnitude to the direct effects associated with the corresponding technologies, indicating their significant contribution to the total employment effects. Moreover, Table 5 presents a sectoral distribution of the total estimated employment effects for each RES technology, highlighting those economic sectors that will mainly benefit from the rapid growth of RES.

3.2. Monetization of employment benefits

The economic valuation of the employment benefits has been estimated according to the proposed methodological framework on the basis of the "opportunity cost of labour" approach. As it is mentioned in Section 2.2 this approach focuses on the possible employment benefits of the newly employed workers, who were previously involuntarily unemployed. For the purposes of our study, the share of newly employed workers that were previously unemployed is estimated on the basis of the function proposed by Haveman and Krutilla [28] using the best estimates (Fig. 1). The definition of the geographical distribution of the direct, indirect and induced employment effects associated with the examined electricity generation technologies is important for the implementation of the proposed methodological framework. So, it is considered that the main activities of the biomass and hydroelectric cycle are realized in the Western Macedonia region, where the major domestic corresponding deposits are located, the wind and photovoltaic units are assumed to be installed in Central Greece, as a number of new units are scheduled in this area in order to cover the loads of the urban centre of Athens and finally the geothermal unit was set to the region of the islands of Southern Aegean in order to be exploited the significant existing geothermal potential. The rates of unemployment in these examined regions and the corresponding estimated probabilities the newly employed workers to be previously unemployed are presented in Table 6. Finally, it was assumed that the 90% of the direct employment effects are created at local scale, while the rest 10% of the direct effects and the 100%

Table 6
Regional rates of unemployment in Greece and estimated probabilities the newly employed workers to be previously unemployed.

	Unemployment (%)	Probability (%)
Greece	10.6	22.5
Western Macedonia	16.0	66.7
Central Greece	11.7	33.3
Southern Aegean	11.0	25.8

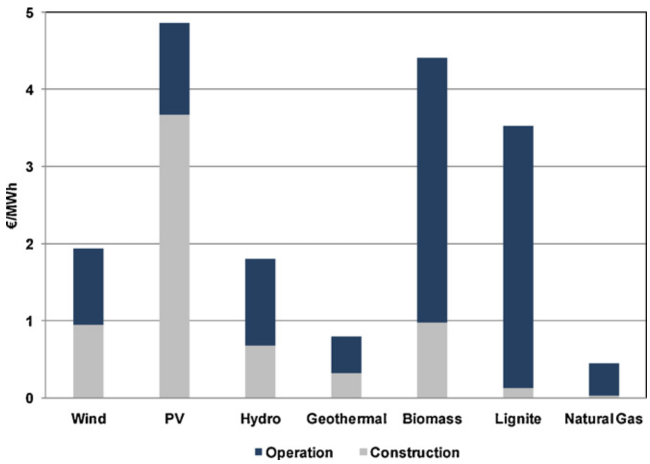


Fig. 2. Economic valuation of employment effects.

of the indirect and induced employment effects concern the entire national economy.

Table 7 summarizes the estimated employment benefits for all RES technologies examined. The highest employment benefits in monetary terms are detected for the case of photovoltaic and biomass energy, which are equal to 4.9 and 4.4 €/MWh correspondingly. Wind and hydro fuel cycles appear to have similar employment benefits (1.9 and 1.8 €/MWh correspondingly), while the geothermal energy the lowest estimates (0.8 €/MWh).

As clearly depicted in Fig. 2, the construction stage contributes more to the total employment benefits for the case of photovoltaic unit (76%) and less for the case of biomass (22%).

Extremely interesting is also, the comparison of the employment benefits associated with the examined RES technologies with the corresponding results for the conventional fuel cycles of lignite and natural gas as they calculated in Tourkolias et al. [23], which are also presented in Fig. 2. It is clearly depicted that photovoltaic and biomass technologies are characterized by higher employment benefits than lignite fuel cycle, while all RES technologies appear more significant impacts on the creation of employment than natural gas fuel cycle.

4. Analysis of uncertainties

It should be noted that the results presented in the previous section are characterized by significant uncertainties and one should consider them only as indicative approximations of the employment benefits associated with the development of RES in Greece.

Uncertainties exist in all stages of the applied methodological framework:

- As regards direct employment effects, the labour input requirements for the development of energy projects are highly site-specific and may vary significantly even for projects that exploit the same technology. Furthermore, in the context of this analysis the direct employment associated with the exploitation of the RES technologies is estimated on the basis of the distribution of spending to the various sectors of the economy instead of using employment data that have been recorded in specific energy projects. So, for each technology the level of spending, its distribution to the various economic sectors and the fact that the input–output table describes the average situation in each economic sector rather than the specific characteristics of an industrial unit that is engaged in development and operation of a RES project, add significant uncertainties to our analysis. Last, another crucial point for the estimation of the direct employment is to what extent the manufacturing of the necessary equipment is produced domestically or is imported from abroad.
- The estimated indirect and induced employment effects associated with the examined energy technologies present also significant uncertainties that are mainly attributed to the assumptions and restrictions of the input–output methodology (see Section 2.1.1).
- The estimation of the probability (P) for a new job created by the realization of an investment to be covered by a worker previously unemployed is of particular importance in the "opportunity cost of labour" approach, and presents substantial uncertainties. Furthermore, the income parameters of the workers in various sectors of the economy, the value of leisure time and the health-related impacts associated with unemployment are additional sources of uncertainty.

Various sensitivity analyses were undertaken in the context of this study in order to investigate the influence of some key parameters to the final results. Specifically, the following scenarios were quantitatively investigated:

4.1. Scenario A: the basic RES equipment is imported from abroad

As already mentioned previously, a critical issue for the analysis is to what extent the manufacturing of the equipment will be undertaken domestically (even in this case parts of the equipment and some of the necessary raw materials will be imported) or this equipment will be almost entirely imported from abroad, influencing significantly the total level of the investment that will be spent domestically. Scenario A assumes that the main elements of the necessary equipment for the development of the various RES projects will be purchased outside the Greece. As a result, for each examined technology the level of the investment in the sectors of "Machinery and equipment", "Electrical machinery" and "Rubber and plastic products" is set equal to zero during the construction stage. The results obtained from such an analysis are presented in Table 8, where it is obvious the significant reduction of the employment effects in construction stage for the case of photovoltaic energy (34%) and wind energy (31%). The reduction is lower in other RES technologies.

4.2. Scenario B: decrease of the investment cost of specific RES technologies

The various RES technologies examined in this paper are characterized by different levels of commercial maturity. Thus, while the cost of wind and hydro turbines has been stabilized at specific

Table 7
Estimated economic values of employment benefits for the examined RES technologies (€/MWh).

	Wind		PV		Hydro		Geothermal		Biomass	
	Construction	Operation	Construction	Operation	Construction	Operation	Construction	Operation	Construction	Operation
Direct	0.55	0.63	2.12	0.78	0.49	0.88	0.17	0.28	0.71	2.70
Indirect	0.24	0.17	0.92	0.17	0.11	0.11	0.09	0.09	0.16	0.38
Induced	0.16	0.18	0.63	0.24	0.08	0.13	0.06	0.10	0.11	0.33
Total	0.95	0.99	3.67	1.18	0.68	1.13	0.32	0.47	0.98	3.42

Table 8
Estimated employment effects related to the construction stage of the examined RES technologies in Greece, according to scenario A.

	Wind		PV		Hydro		Geothermal		Biomass	
	Man-years/MW	Man-years/TWh	Man-years/MW	Man-years/TWh	Man-years/MW	Man-years/TWh	Man-years/MW	Man-years/TWh	Man-years/MW	Man-years/TWh
Direct	6.1	112.3	11.2	398.8	13.3	75.7	10.2	47.6	19.7	92.0
Indirect	3.3	61.1	6.5	231.0	6.3	35.9	5.6	26.1	9.7	45.4
Induced	2.5	44.8	4.6	162.9	5.0	28.3	4.4	20.6	7.4	34.6
Total	11.9	218.2	22.2	792.7	24.5	139.9	20.2	94.3	36.9	171.9

levels and is mainly influenced by the costs of raw materials used, the labour expenses, etc., the development of the global markets for photovoltaic, geothermal and biomass power units may result in significant cost reductions of those technologies in the upcoming decade. In scenario B, we have examined the impacts on employment benefits from a radical decrease of the investment cost of these RES technologies, which are characterized as less mature at technological level in Greece. More specifically, the investment cost of photovoltaic energy was set equal to 1800 €/kWel as a result of a radical decrease in the cost of the equipment, while the purchasing cost of the equipment for geothermal and biomass units was decreased by 30%. The results (Table 9) led to a 21% reduction of employment effects in physical terms in construction stage for the case of photovoltaic energy, while for geothermal and biomass energy the reduction was lower and equal to 12% and 8% correspondingly.

4.3. Scenario C: high share of employed persons that were previously unemployed

Scenario C deals with the variation of the employment benefits associated with the projects in question as regards the share of employed persons that were previously unemployed. As Greece and other European countries enter in a period with relatively high unemployment rates, the creation of new employment may be of particular importance for both the governments and the public. So, this scenario was formulated on the basis of the upper-bound of the function proposed by Haveman and Krutilla [28] (Fig. 1), assuming that during the development and operation of the energy projects in question the share of the employed persons that were previously unemployed is higher.

4.4. Scenario D: monetization of employment benefits through the "public expenditures" approach

In our base case analysis the monetization of employment benefits was elaborated through the "opportunity cost of labour" approach, making specific assumptions for various parameters such as the income of the workers in various sectors of the economy, the value of leisure time, and the health-related impacts associated with unemployment. In order to examine the sensitivity of the results as regards these parameters, scenario D exploits the "public expenditures" approach for the economic valuation of the employment benefits. The "public expenditures" approach is based on the willingness to pay of the central government authorities for creating extra employment, revealed through various tax and subsidy schemes [16]. The rationale behind this assumption is that the government's willingness to pay to create extra employment reflects public preferences for employment increases, given that the government promotes and supports the public interest with appropriate projects and policies. As a result this approach assumes that the economic value of increased employment, due to the realization of a project or policy, can be based on the revealed willingness to pay of the government to create one man-year of extra employment.

This approach has been implemented in Greece in our previous work for the estimation of the employment benefits associated with fossil-fuelled power plants [23]. The basic assumptions of this implementation are also exploited in the present study. Analyzing several programmes funded by the Greek government, it was found that the public expenditures for creating one man-year of extra employment ranges from 4000 € to 12,000 €, with a weighted average estimated at 6400 € per man-year of employment. This latter value is used in the context of this scenario for estimating the economic benefits of employment.

Table 9
Estimated employment effects related to the construction stage of the examined RES technologies in Greece, according to scenario B.

	PV		Geothermal		Biomass	
	Man-years/MW	Man-years/TWh	Man-years/MW	Man-years/TWh	Man-years/MW	Man-years/TWh
Direct	13.8	490.7	11.5	53.4	23.1	107.6
Indirect	7.2	258.0	5.9	27.3	11.2	52.2
Induced	5.6	199.1	4.9	22.7	8.8	41.1
Total	26.6	947.8	22.2	103.4	43.1	200.9

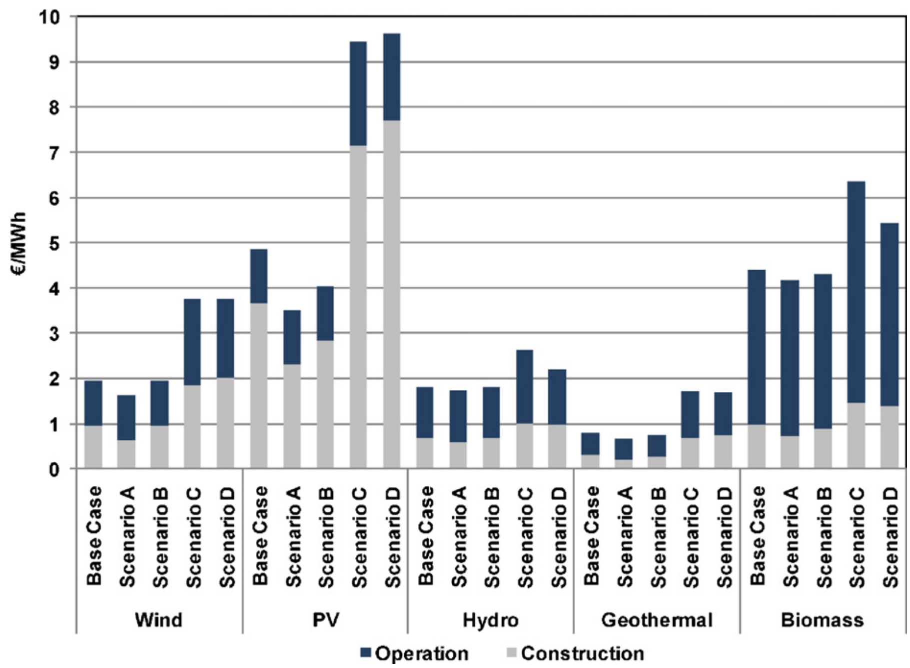


Fig. 3. Sensitivity analysis for the employment benefits associated with the utilization of RES technologies in Greece (in €/MWh).

Fig. 3 presents comparatively the employment benefits associated with the RES technologies in question for all the scenarios examined. The obtained results show that under all examined scenarios the photovoltaic and biomass units present the most significant employment benefits per unit of electricity generated. Their range for the photovoltaic cycle is between 3.5 and 9.6 €/MWh, while for the biomass cycle between 4.2 and 6.3 €/MWh. Wind and hydro energy have almost identical fluctuation on employment benefits amounting to 1.6–3.8 €/MWh and 1.7–2.6 €/MWh correspondingly, while geothermal units are characterized by relatively lower employment benefits among the examined RES technologies (0.7–1.7 €/MWh).

5. Concluding remarks

The large scale utilization of RES in Europe and Greece during the upcoming decade in the context of the European energy and climate package is expected to have significant implications on the macroeconomic environment at regional and national levels, influencing both, the employment rates and the overall economic development. This paper focuses on the employment benefits associated with the development of various RES technologies in Greece, formulating and implementing an integrated approach for their quantification. The proposed approach comprises two basic steps. Firstly, by using the input–output methodology the direct, indirect and induced employment effects associated with the development and operation of various RES technologies are quantified and expressed in terms of man-years of labour requirement per TWh of electricity generated or per MW of installed capacity. Secondly, the previously estimated employment effects are expressed in monetary terms by using the "opportunity cost of labour" approach.

Attributing monetary values to the employment effects associated with the realization of energy projects, seems to form a powerful tool for incorporating a number of social concerns and particularly those related to the creation of employment, in the decision-making process. More specifically, expressing all costs and benefits (whether private or external) into a common measuring unit (i.e. monetary value), provides the advantage of using a single measure of the attractiveness of an alternative option, compared to other assessment techniques such as multi-criteria analysis. Thus, assessing the estimated employment benefits of a project in conjunction with its environmental externalities and the traditional financial analysis provide a sound basis for improving the quality of cost–benefit analyses in the energy sector, highlighting those technologies, policies, scenarios, etc., that maximize the social welfare.

The developed approach is implemented for assessing the employment benefits associated with five basic RES technologies, which are expected to play a significant role in the Greek power system during the upcoming decade, namely wind, photovoltaic, hydro, geothermal and biomass power units. Both the construction and the operation phases are included in this analysis.

The results clearly show that the development of RES technologies have significant employment implications. According to the base case scenario, the most significant employment benefits were estimated for photovoltaic and biomass power units, amounting to 4.9 and 4.4 €/MWh, correspondingly. Wind farms and hydro units

present also significant employment benefits estimated at 1.9 and 1.8 €/MWh correspondingly, while the geothermal energy is characterized by relatively lower employment benefits (0.8 €/MWh).

The obtained results are site- and technology-specific, and therefore cannot be easily generalized and exploited in other case studies. Their reliability was examined in the context of this paper through several sensitivity analyses, highlighting various policy dimensions. The realization of a significant part of the manufacturing activities domestically is a prerequisite for maximizing the positive socio-economic effects of the development of RES in the national economy. Also, the estimated employment benefits are strongly influenced by the local/national economic conditions (i.e. unemployment rates, etc.), which affect the share of employed persons that were previously unemployed, or the government's willingness to pay for creating one extra man-year of employment.

More generally, the implementation of the proposed methodological framework, combined with other tools and approaches that quantify the environmental externalities associated with different power generation technologies, provide a background for more robust arguments to the dispute about the preferable expansion pattern of the electricity system, where worries for unemployment risks are set against environmental concerns. Selection of technologies and appropriate sitting are significant energy planning issues and the utilization of such tools may improve the decision making process.

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